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Jun Yang

Institute of Refrigeration and Cryogenics

Shanghai Hitachi Electrical Appliances Co., Ltd, China, Peoples Republic of Long Zhang

Shanghai Hitachi Electrical Appliances Co.

Li Zhang

Shanghai Hitachi Electrical Appliances Co.

Hao Yuan Li

Shanghai Hitachi Electrical Appliances Co.

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Development of a Two-Cylinder Rolling Piston CO₂ Expander

J. YANG^(1,2), L. ZHANG⁽²⁾, LI ZHANG⁽²⁾, H.Y. LI⁽²⁾

⁽¹⁾ Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University,
Shanghai, 200030, P.R. China

⁽²⁾ R&D Centre, Shanghai Hitachi Electrical Appliances Co., Ltd.,
Shanghai, 201206, P.R. China,

Tel: 86-21-58548888, Fax: 86-21-58991084, E-Mail: yangj@shhec.com.cn

ABSTRACT

Carbon dioxide (CO₂) as a natural refrigerant is one candidate alternative to HFC refrigerants. But CO₂ system has lower efficiency and is not yet competitive concerning the COP. The most effective method to improve the efficiency of the transcritical CO₂ system is to replace the throttling device with an expander. In this paper, a two-cylinder rolling piston expander without inlet valve has been developed. In order to understand the work process of this expander, the prototypes installed with sensors have been made, and a test rig for the expander was built. The working performance were tested at different operating conditions, and the results were analyzed.

1. INTRODUCTION

The natural working fluid CO₂ (Carbon dioxide) is inexpensive, widely available and not flammable or toxic. Furthermore, it has the environmental advantage (ODP=0, OWP=1). But in the CO₂ refrigerating system, there is a large throttling thermodynamic loss associated with the throttling process. How to recover throttling loss efficiently is the key point to increase the COP. The expander replacing the throttle valve is considered to be a high effective way. Various types of the expander were proposed in the past decade. The feasibility of a vane type expander was studied, the performance of the expander for the CO₂ cycle is being clarified theoretically and experimentally (Fukuta et al. 2000, 2001, 2003, Shaoyi Sun et al. 2008). A twin screw expander combined with a compressor was also developed (Stosic et al. 2002). The scroll expanders were studied and experimented too (Detlef Westphalen et al. 2004, Fukuta et al. 2006, Hirokatsu KOHSOKABE et al 2008, Hideaki NAGATA et al. 2010). The rolling piston expander has been researched yet (Xianyang Zheng et al. 2007).

In this paper, the new type of two cylinder rolling piston expander is developed and tested. Figure 1 shows the schematic view of the expander and picture of prototype. This expander consists of two expansion units, which are named the first expansion unit and the second expansion unit separately. Similar to the twin cylinder rolling piston compressor, each expansion unit is made up of cylinder, rolling piston (roller), vane, spring, bearing and intermediate plate. For the first expansion unit, the rolling piston and the vane divide the space between cylinder inner wall and rolling piston outer surface into two chambers: suction chamber and the first expansion chamber. For the second expansion unit, this space is divided into two chambers: the second expansion chamber and discharge chamber. The expansion chambers in the first expansion unit and second expansion unit are linked with a hole in the intermediate plate, therefore the two expansion chambers constitute the expansion chamber of the expander. In order to realize the expansion process, the displacement of the second expansion unit is larger than that of the first expansion unit.

The two expansion units use a common crankshaft which has two eccentricities in the different direction. The included angel of two eccentricities is determined by the angle α and β . When first eccentricity operates in the angle α , the second eccentricity needs to operate out of the angle β , so that the run-through phenomenon can be avoided in the operation. When the expander is assembled, the first discharge port matches second suction port by the through hole in the intermediate plate vertically, so that the through hole becomes a straight one, which is good for improvement of volumetric efficiency. The included angle of two vanes is adjusted to fit it.

For this expander, a complete cycle includes three working processes. Suction process, expansion process and discharge process. Compared with the traditional rolling piston expander, the suction valve of this expander can be removed, then the expansion process becomes continuous and the reliability and performance of expander could be improved.

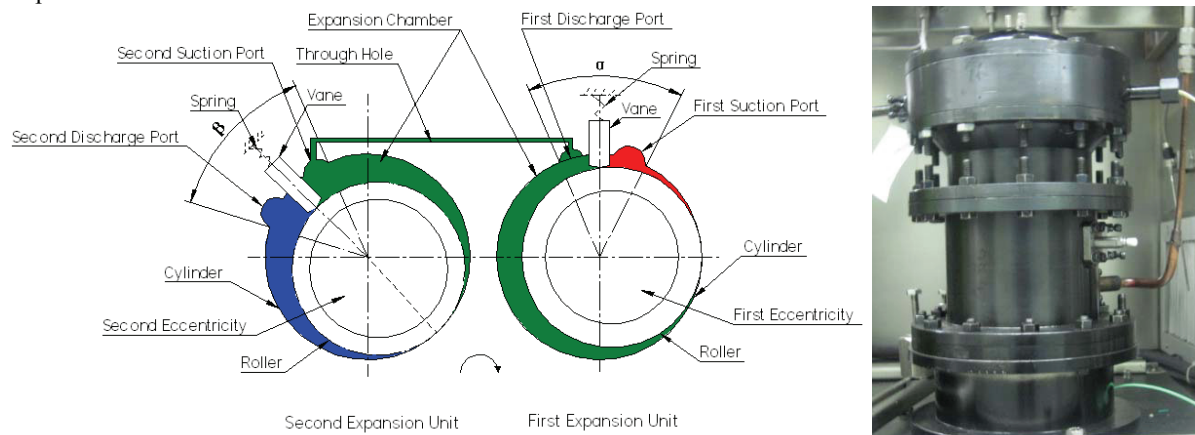


Fig.1 The schematic view of Expander and Picture of Prototype

2. EXPERIMENTAL SET-UP

Fig.2 shows the CO₂ trans-critical system with expander. It consists of a CO₂ speed variable compressor, gas cooler, mass flow meter, throttle valve, evaporator, cooling water system, data acquisition system and so on. The mass flow meter is used to measure the refrigerant mass flow rate; The inlet pressure is controlled by the throttle valve; the speed variable compressor supply different refrigerant mass flow rate; The inlet temperature of expander can be guaranteed by controlling water rate of gas cooler. It can be operated automatically and manually.

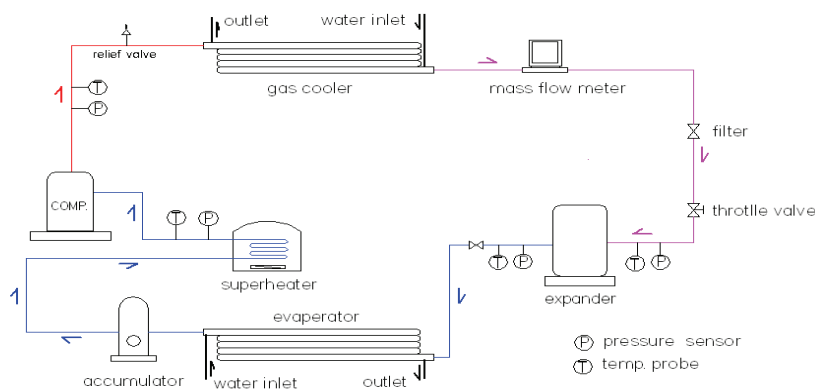


Fig. 2 Schematic View of Test Rig

3. EXPERIMENTAL RESULTS ANALYSIS

3.1 Influences of Rotational Speed

The target of development of expander is to recover the throttle loss efficiently, and expander may operate in different rotational speed, in order to get the influence of rotational speed on operational parameters, the rotational speed works as variable in the following discussion.

Fig3 shows the effects of rotational speed of expander. In the experiment, the inlet pressure of expander is about 7.2MPa, the outlet pressure is approximate 4.6MPa, and suction temperature is 37 °C, the rotational speed is from 1300 to 3100rpm.

As shown in fig.3, with the increasing of the rotational speed of expander, the volumetric efficiency (η_v) and mass flow rate increases simultaneously, but the expansion power and the isentropic efficiency (η_{ex}) decrease. As we know, there is smaller leakage and more friction work with increasing of rotational speed of expander, so the volumetric efficiency (η_v) is higher and the isentropic efficiency (η_{ex}) become lower.

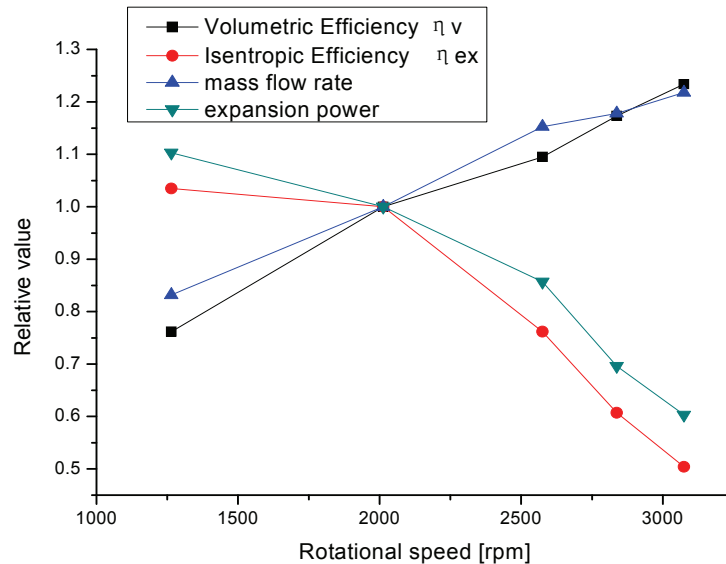


Fig. 3 the Influences of Expander Rotational Speed

3.2 Influences of Pressure Ratio

In this experiment, the inlet condition is same as above, and the rotational speed is about 2000rpm. The pressure ratio is changed by controlling outlet pressure.

As seen in fig.4, higher pressure ratio, more leakage, so the volumetric efficiency (η_v) becomes smaller as pressure ratio increases. In order to keep rotational speed constantly, more load (expansion power) should be needed for expander when pressure ratio rise, and the isentropic efficiency (η_{ex}) becomes higher at the same time. Mass flow rate changes unobvious.

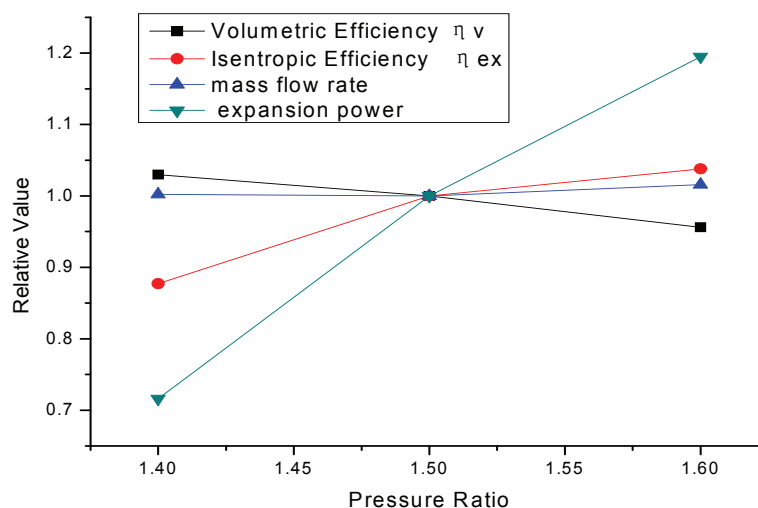


Fig.4 the Influences of Pressure Ratio

3.3 Influences of Inlet Temperature

In the test, the inlet pressure of expander is about 7.2MPa, the outlet pressure is approximate 4.9MPa, and expander inlet temperatures are 35, 37, and 39°C, the rotational speed is about 2000rpm.

The below figure 5 show the influences of the inlet temperature. With the increasing of inlet temperature, mass flow rate decreases. There is optimum value for expansion power and isentropic efficiency at the inlet temperature of 37°C and there is unobvious change of volumetric efficiency.

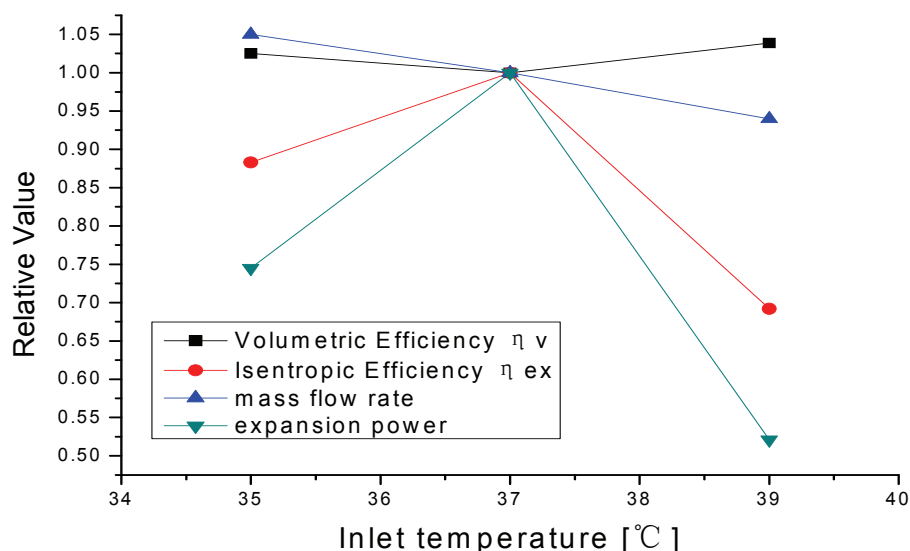


Fig.5 Influences of Inlet Temperature

4. CONCLUSIONS

In this paper, a new two-cylinder rolling piston expander has been proposed and tested, and a test rig for the expander was built. The expander don't have inlet valve and run-through phenomenon is avoided, at the same time, the through hole is optimized to improve the volumetric efficiency. In the tested operating condition, some optimum value of parameters is obtained.

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